RELATIONSHIP OF THE CHEMICAL CONSTITUTION OF ETHOXYLATED FATTY ACID ESTERS OF SORBITOL AND THEIR ANTISTATIC PROPERTIES WHEN APPLIED TO POLYPROPYLENE CARPETING

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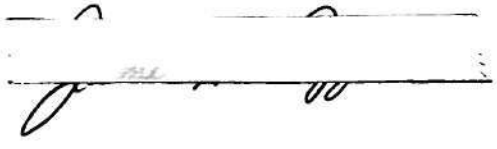

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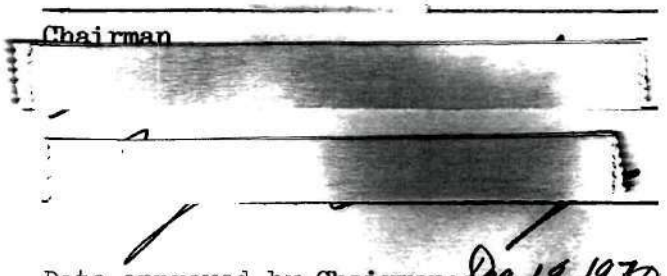

Chairman

Date approved by Chairman: Dec. 19, 1969

DEDICATED

To my wonderful wife, Sheryl and to my parents, Mr. and Mrs. Howard Pepper.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

The objective of this work was to determine systematically the effectiveness of non-ionic surface active chemicals in altering the static charge on polypropylene carpeting. The non-ionic chemicals chosen for this work were mono- and tri- fatty acid esters of sorbitol with differing degrees of ethoxylation.

By varying the degree of esterification, the length of the fatty acid chain, and the degree of ethoxylation, a broad spectrum of non-ionic compounds are available which range from those which are very hydrophilic (water-loving) to those which are very lipophilic (oil-loving).

For measuring the static build-up and decay, a field mill and Rothschild recorder were used. Measurements were conducted at different levels of relative humidity in order to evaluate the effect of humidity on static charge build-up and decay.

The most important conclusions which can be drawn from this work are that chemical modifications of sorbitol which increase its hydrophilic nature results in a lowering of the static charge that can be generated on polypropylene carpets. The extent of static charge reduction is a function of the hydrophilic-lipophilic nature of the finish, the amount of finish, and the conditions of relative humidity under which the measurements are made.

CHAPTER I

INTRODUCTION

Static electricity and some of its effects were described as early as 600 B.C. by Thales of Miletus who noted that amber, after being rubbed with silk, attracted small particles of dust. From the Greek word for amber, "elektron", came the word electricity.[1]

It was not until the eighteenth century that an understanding of the nature of electricity came from the study of electric charges. In 1752 Benjamin Franklin proved that lightning was a phenomenon of static electricity. He further named the kind of electricity produced when a glass rod is rubbed with silk "positive" and the kind that appears when hard rubber is rubbed with fur "negative" since the two charged materials attract each other.[2]

In 1759, Robert Symmer noted that when he wore silk stockings over his wool ones, sufficient electricity was generated in taking the stockings off to cause them to inflate and to repel each other.[3]

Charles Augustin de Coulomb (1736-1806) was the first to publish a quantitative law about static charges and to offer experimental proof. Coulomb's law or the "inverse square law" states that the electrostatic attraction or repulsion between two charged bodies is directly proportional to the product of the charges and is inversely proportional to the square of the distance between them.[4]

Later, Helmholtz (1821-1894) introduced the contact potential

theory of electrification of insulators. This basic concept of static electrification assumes that when two bodies are placed in contact there is a transfer of charge from one body to the other. The transfer forms an "electrical double layer" consisting of two layers of charge of opposite sign, one on or very near each surface, and separated by only a few Angstrom units.[5]

Probably the most important research in the first half of this century was done by P.E. Shaw. He showed the important influences that the chemical and physical conditions of the surfaces have in the generation of static electricity.[6]

During the past two decades, with the rapid development and use of synthetic fibers, there has been a great deal of interest focused on the static properties of fibers and methods for controlling the charge build-up or dissipating the charge once it has occurred. Methods for controlling static electricity include:[7]

(1) Maintenance of high atmospheric humidity.

(2) Ionization of surrounding atmosphere with ratio-active materials.

(3) Ionization of surrounding atmosphere with electrical discharge.

(4) Use of conducting materials.

(5) Use of antistatic agents.

The use of humidification for controlling static problems with hydrophobic fibers is one approach but high humidities are required.

In addition, high humidities may adversely affect fiber properties and processing performance.[8]

Because of health hazards to operators, static eliminators based on radio-active ionization of the atmosphere must be kept at low levels and confined to localized areas. Once the static-prone material passes through the zone of the eliminator it immediately becomes vulnerable to static.[9]

The static eliminators based on ionization of the atmosphere with an electrical discharge, while effective, are expensive and constitute a potential fire hazard. As with radio-active eliminators, they must be installed at every point where static build-up can occur.[10]

Conductive metals can be incorporated into the textile material, for example, in airplane upholstry and in carpeting. Schilling[11] prepared carpet yarn containing stainless steel wire and wool and measured the static charge build-up. He reported that there was a significant drop in the static charge build-up in those samples which contained the stainless steel wire. The use of conductive metals is very effective, but is expensive and may adversely effect some of the desirable properties of the textile material.[12]

The products developed as antistatic agents for fibers are organic compounds which are surface-active. The antistatic agents can be classified according to the charge of the surface active portion of the molecule. Thus, antistatic agents can be classed as anionic, cationic, non-ionic, or amphoteric compounds.[13]

With anionic compounds the active portion of the molecule is

negatively charged on dissociation. Typical anionic compounds include:[14]

1. Fatty acid salts
   - Sodium
   - Potassium
   - Amine
2. Sulfates
   - sulfated triglycerides
   - sulfated fatty acids
   - sulfated fatty acid esters
   - sulfated fatty alcohols
   - sulfated fatty alcohol ethoxylates
   - sulfated fatty amides
3. Phosphate esters of
   - alcohols
   - polyoxyethylenated aliphatic alcohols
   - polyoxyethylenated alkyl phenols
4. Aliphatic Sulfonate salts

Although many of the anionics exhibit antistatic properties, only a few are highly effective on hydrophobic fibers. Some anionic agents show good substantivity for certain textile fibers, and a number of anionic compounds are good softners.[15]

Cationic antistatic agents, when dissolved in water, dissociate into an active ion that is positively charged. These compounds are easily absorbed on many of the textile fibers and are noted for their substantivity.[16] Some cationics may cause skin irritation and may adversely effect the light fastness of some dyes. Typical cationic compounds include:

1. Organic acid salts of

   alkylamines
   alkylamides
   alkylimidazoles

2. Quaternary ammonium compounds

   morpholinium derivatives

Non-ionic compounds as a class of antistatic agents are incapable of dissociating into ions in water. They are available in a wide range of solubilities, and many of these compounds have useful lubricating properties on textile fibers. Important members of this class include:[17]

1. Ethylene oxide derivatives of

   fatty acids
   fatty alcohols
   alkylphenols
   alkylamines
   alkylamides

2. Amide-like compounds

   alkanolamides

3. Polyols

   polyethylene glycol

4. Polyhydric compounds (other than polyols)

   sorbitol
   trimethylol propane
   sorbitol monolaurate

Amphoteric compounds contain both acidic and basic groups in the molecule and depending on the pH of the solution can dissociate into either positively or negatively charged ions. Some amphoteric compounds have antistatic properties. Aminocarboxylic acids are important members of this class that can be used as antistatic agents.[18]

Statement of Problem

Static electricity presents a problem in the winding, warping, and weaving of synthetic yarns, and constitutes a potential hazard where oxygen or other gases are in use, for example, in hospital operating rooms. Materials charged by static electrification can also attract small particles of dirt or dust. Consequently, there has been a great deal of interest focused on methods used to suppress static build-up or increase the rate of dissipation of charge once it has occurred.

Frequently non-ionic compounds are used as non-durable antistatic finishes for various synthetic fibers. Non-ionic compounds are also used as lubricants, wetting agents, and softeners.

The objective of this work is to determine systematically the effectiveness of non-ionic surface active chemicals in altering the static charge on polypropylene carpeting. The non-ionic chemicals chosen for this work were mono- and tri- fatty acid esters of sorbitol with differing degrees of ethoxylation. Lauric, palmitic, stearic, and oleic acids were reacted with sorbitol to form the long chain fatty acid esters. These esters can be ethoxylated using ethylene oxide. In this work, the materials were ethoxylated to the extent of 4 or 5 moles and 20 moles of ethylene oxide per mole of sorbitol.

By varying the amount of fatty acid, the length of the fatty acid chain, and the amount of ethylene oxide, a spectrum of non-ionic compounds was available which ranged from those which are very hydrophilic (water-loving) to those which are very lipophilic

(oil-loving). These non-ionic compounds were commercially available and were obtained from Atlas Chemical Industries, Inc. The spectrum of properties represented by these compounds was completed by using polyethylene glycol, which is very hydrophilic and mineral oil which is very lipophilic. The objective of this work was to determine which of the factors is responsible for reducing the extent of static charge build-up and its dissipation.

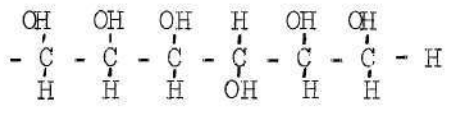
CHAPTER II

MATERIALS AND INSTRUMENTATION

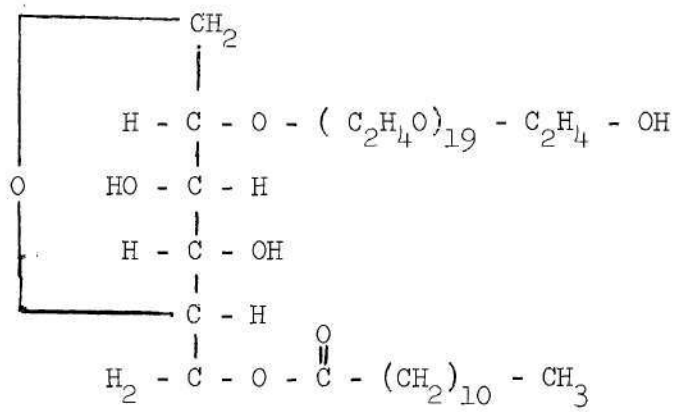
Materials

The polypropylene carpet samples that were used in this investigation were all of the same construction. The face yarn was mass pigmented split film polypropylene. The samples were tufted, had a looped pile height of 0.330 inches, weighed 19.3 ounces per square yard, and had a split film polypropylene primary backing.

The samples differed from one another by the antistatic finish that was applied to them. The finishes were non-ionic derivatives of sorbitol. Sorbitol is represented by the chemical formula $C_6H_8(OH)_6$:



Because of its hydroxyl groups, sorbitol can be esterified by reaction with organic acids and ethoxylated by a reaction with ethylene oxide. Lauric, palmitic, stearic, and oleic acids were reacted with sorbitol to form mono- and tri- esters. Non-ionic finishes with no ethylene oxide, four or five moles of ethylene oxide, and 20 moles of ethylene oxide per mole of sorbitol were used in this investigation. A typical finish which is ethoxylated and esterified is polyoxyethylene (20) sorbitan monolaurate:



A chemical description of the non-ionic finishes is summarized in Table 1. Three other materials were used: polyethylene glycol (Carbowax 400), mineral oil, and Atlas G-263 which is a cationic antistatic finish. The chemical name for G-263 is N-cetyl-N-ethyl morpholinium ethosulfate.

Table 1.
Derivatives of Sorbitol

Moles EtO *	Mono - Ester				Tri - Ester			
	Lauric	Palmitic	Stearic	Oleic	Lauric	Palmitic	Stearic	Oleic
0	X	X	X	X	—	—	X	X
4 or 5	X	—	X	X	—	—	—	—
20	X	X	X	X	—	—	X	X

X Represents the materials used in this study

* moles of EtO per mole of Sorbitol

Instrumentation

The static generating device was enclosed in a constant temperature and humidity cabinet. The static charge build-up and decay was measured

using a device called a "field mill". A Rothschild recorder was attached to the field mill to obtain a permanent record of the measurements.

The static generating device consisted of a masonite disk, 15 inches in diameter, which was mounted on a shaft. The disk and shaft were driven by a variable speed motor capable of producing 10 to 280 revolutions per minute.

Facing the right side of the masonite disk was an aluminum frame consisting of two rows of vertical bars and two rows of horizontal bars which supported a clamp that held the leather rubbing device against the carpet sample. A one thousand gram weight was attached to the clamp to keep a constant pressure on the carpet sample. A wire was also attached to the clamp so that the leather could be removed from the carpet to begin the static decay process without opening the humidity cabinet.

On the left side of the masonite disk were located two vertical aluminum bars with one horizontal bar. This frame supported the sensing head of the field mill. The sensing head was held tightly by a clamp which was screwed to the aluminum supporting frame. A constant distance of 3.4 centimeters was kept between the sensing head and the carpet sample for all measurements.

The principle of the field mill was described as early as 1943 by Schwenkhagen; however, many modifications have been made since that time.[19] Today, according to Gayler, Wiggins, and Arthur, " the field mill is the most accurate and reliable system to measure static by induction. It is also the most convenient, accurate, and trouble free instrument available for measuring static even when operated by unskilled personnel." [20]

In the operation of the field mill, the electrostatic field formed between the sensing electrode and the charged surface is chopped by a grounded rotating shield. The name "field mill" given to this type of instrument comes from the chopping or milling of the electrostatic field. The chopping of the electrostatic field induces a square wave potential on the sensing electrode, the amplitude of which is proportional to the field strength. This signal can be amplified and read directly using an a.c. vacuum tube voltmeter.[21]

The "field mill" provides a measure of the magnitude of the electric field strength expressed in volts/meter (v/m). Since, in this work, the geometry of the specimens as well as the conditions of test were kept constant, one can consider the electric field strength as a measure of the magnitude of the electrostatic charge density. In the remainder of this thesis reference is made to the term "static charge" which is actually a relative electrostatic charge density as determined by the electrostatic field strength.

The generating disk, the leather rubbing device, and the field mill sensing head were enclosed in a constant temperature and humidity cabinet* so a range of humidities could be obtained. The desired humidity was obtained by adjusting the dry-bulb and wet-bulb temperatures. Chilled water 44 degrees Fahrenheit, from the air conditioning system of the A. French Textile School Building was used as the cooling media. The front of the

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* Counter Flow Combination Temperature and Humidity Cabinet, Manufactured by Blue M Electric Co.

temperature and humidity cabinet was a sealed glass door which made it possible to observe the measurement that was in progress.

CHAPTER III

EXPERIMENTAL PROCEDURES

Before any of the antistatic finishes could be applied to the carpet samples the commercial finishes that were on them had to be removed. This was accomplished by a Soxhlet extraction process using chloroform as the solvent. The carpet samples were extracted for a period of three hours which corresponded to approximately ten extraction cycles. After extraction, the samples were dried by evaporation for at least 24 hours.

After the polypropylene carpet samples had dried they were ready for application of the various antistatic finishes. Every finish was applied at 78 degrees Fahrenheit plus or minus two degrees Fahrenheit for 90 minutes. A 25 to 1 liquor to fiber ratio was used for all applications. Three concentrations were used in this investigation: two per cent, one half per cent, and one quarter per cent based on the weight of fiber. The wet pick up was adjusted to 100 per cent by passing the carpet samples through an automatic wringer until the proper amount of solution was retained by the sample. After the wet pick up was measured, the carpet samples were dried by evaporation for 24 hours. The carpet samples were then conditioned at the desired humidity.

Each of the carpet samples to which finishes had been applied was cut into two parts to facilitate mounting and then mounted on the masonite disk by means of rubber cement. While the rubber cement was drying the field mill and recorder were calibrated. Thereafter, the dry-bulb and wet-

bulb dials were set to the desired temperatures. When the dry-bulb and wet-bulb thermometers inside the cabinet indicated that the desired temperatures had been reached, the test sample was conditioned for four hours. There was adequate space in the temperature and humidity cabinet for four samples to condition simultaneously.

Before making any measurements the field mill was allowed to warm up for at least 10 minutes. After the carpet sample had been conditioned to the proper humidity and the field mill was warm, the wire connected to the leather rubbing device was loosened so that the leather would be pressed against the carpet sample. A 1000 gram weight was used to hold the leather rubbing device against the carpet sample with a constant pressure.

To start the static build-up measurements, the variable speed motor was adjusted so that the disk would rotate at 28 revolutions per minute. At the same time, a stop watch was activated. The carpet sample was charged for 15 minutes and the static build-up was recorded after 30 seconds, after one minute, and every minute thereafter until a total of 15 minutes had elapsed. After 15 minutes, the leather charging material was pulled away from the carpet sample. With the pressure removed, the rotational speed of the masonite disk increased to 52 r.p.m. The decay process was initiated the instant the leather rubbing device was pulled away from the carpet sample. The decay was measured after 30 seconds, after one minute, and every minute thereafter until 15 minutes had elapsed

The temperature for all measurements was held constant at 80 degrees Fahrenheit and three different relative humidities were used: 40 per cent, 65 per cent, and 80 per cent. The samples which had high static build-

ups at 65 per cent relative humidity were tested at 80 per cent relative humidity.

To measure the durability of the antistatic finishes, the carpet samples were given a washing treatment. The washing treatment consisted of washing the samples in water in a Launder - O - Meter for one hour at 140 degrees Fahrenheit. This was followed by a cold water rinse, after which a hot water wash at 140 degrees Fahrenheit was repeated. The carpet samples were then dried by evaporation at room temperature.

CHAPTER IV

RESULTS AND DISCUSSION OF RESULTS

The experimental results and discussion which follow will be presented in such a way that the various factors governing the static behavior of the treated carpets can be clearly shown. These factors include the following:

1. degree of esterification of sorbitol
2. degree of ethoxylation of the sorbitol esters
3. chain length of the fatty acids in the sorbitol esters
4. effect of unsaturation in the sorbitol esters
5. concentration of finish
6. relative humidity
7. hydrophilic-lipophilic balance of finish
8. durability of finishes
9. comparison of non-ionic and cationic finishes

In Figures 1 and 2 are shown the static charge (electric field strength) build-up and decay curves for the unfinished control carpet and several of the carpets to which finishes were applied. The shapes of these curves are typical of those obtained for all of the finishes. It is noted that all of the sorbitol derivatives reduce the build-up of the electric field strength and the more lipophilic finishes have the highest field strength. It is also noted that after 15 minutes of decay there is

a substantial residual charge on the carpet samples that were treated with the lipophilic finishes. The ethoxylated finishes representing the more hydrophilic compounds give the lowest charge build-up and no residual charge after 15 minutes of decay. Mineral oil, an extreme case of a lipophilic substance, when applied to polypropylene carpet causes a higher static charge than that for an unfinished carpet.

Effect of Degree of Esterification of Sorbitol

The effect that the degree of esterification of sorbitol has on the antistatic properties of the non-ionic finishes is shown in Table 2. In every case the tri-esters have a higher static charge build-up than the mono-esters. However, with high degrees of ethoxylation the differences between the mono- and tri-esters are significantly reduced.

Likewise, after 15 minutes of static decay, the tri-ester has a higher static charge than the mono-ester. When 20 moles of ethylene oxide are reacted with the mono- and tri-ester, the static charge after 15 minutes of decay is essentially zero.

One explanation for the differences between the mono-esters and the tri-esters is that the mono-esters are more hydrophilic than the tri-esters and thus will absorb more moisture from the atmosphere. The more moisture present on the fiber surface, the greater the electrical conductivity of the fiber surface becomes, resulting in lower static charge build-up and faster dissipation of charge.[22]

Table 2
The Degree of Esterfication and Its Effects on Static Build-up and Decay at 40% Relative Humidity

Finish 2 Per Cent	Build-up*	Decay*
Sorbitan Monostearate	7,200	0
Sorbitan Tristearate	60,700	11,700
Sorbitan Monooleate	4,300	0
Sorbitan Trioleate	26,700	600
Polyoxyethylene (20) Sorbitan Monostearate	1,150	50
Polyoxyethylene (20) Sorbitan Tristearate	1,600	0
Polyoxyethylene (20) Sorbitan Monooleate	1,100	50
Polyoxyethylene (20) Sorbitan Trioleate	1,700	25

* Each measurement was recorded in volts per meter after 15 minutes of build-up and after 15 minutes of decay.

Effect of the Degree of Ethoxylation

The effect of the extent of ethoxylation on the static charge build-up and decay is illustrated in Table 3. There is a progressive decrease in the static build-up with an increase in the degree of ethoxylation. Polyethylene glycol represents the extreme case of a material containing $- CH_2 - CH_2 - O -$ links, and the carpet treated with this material has a much lower static build-up than the carpet treated with the most highly ethoxylated ester of sorbitol.

The static charge after 15 minutes of decay drops from 200 volts per meter to zero when sorbitan monooleate is ethoxylated. After 15 minutes of decay the carpet sample treated with polyethylene glycol had a static charge of 75 volts per meter.

Ethylene oxide is very hydrophilic and increases the moisture adsorption capabilities of the antistatic finish. As the moisture adsorption

capability of the finish is increased, the surface conductivity is also increased. When the surface conductivity is increased, the static charge build-up is reduced and the rate of charge dissipation is increased.

Table 3
The Effect of Ethylene Oxide On Static Build-up and Decay At 65% Relative Humidity

Finish 0.5 Per Cent	Build-Up*	Decay*
Control - No Finish	58,000	32,000
Sorbitan Monooleate	22,800	200
Polyoxyethylene (5) Sorbitan Monooleate	1,350	0
Polyoxyethylene (20) Sorbitan Monooleate	550	0
Polyethylene Glycol	125	75

* Each measurement was recorded in volts per meter after 15 minutes of build-up and after 15 minutes of decay

Effect of Chain Length of the Fatty Acids

The effect that the chain length of the ester derivatives of sorbitol has on the static properties of polypropylene carpets is shown in Table 4. With an increase in the chain length of the fatty acid, there is a corresponding increase in the static charge build-up. However, when ethoxylated, the presence of the - CH_2 - CH_2 - O - links in the finishes becomes the dominant factor in determining the antistatic properties of the finishes, i.e., a much lower static build-up results. The static charge after 15 minutes of decay is the same for all four fatty acid chain lengths.

When the chain length of the fatty acid is increased, the finish becomes more hydrophobic (lipophilic) and thus the surface conductivity

of the fiber is reduced the static charge build-up is increased.

Table 4
The Effect of Chain Length of the Fatty Acid
On Static Build-up and Decay at
40% Relative Humidity

Finish 2%	Build-Up*	Decay*
Sorbitan Monolaurate	600	0
Sorbitan Monopalmitate	2100	0
Sorbitan Monooleate	4300	0
Sorbitan Monostearate	7200	0

* Each measurement was recorded in volts per meter after 15 minutes of static build-up and after 15 minutes of decay.

Effect of Unsaturation in the Fatty Acid Chain

Table 5 includes a comparison between stearate and oleate anti-static finishes. The only difference between the stearate and oleate finishes is that the stearate chain is saturated and the oleate chain is unsaturated, that is, contains a carbon-carbon double bond.

For the finishes which have not been ethoxylated, it is clear that the oleate derivatives of sorbitol exhibit a lower static charge than the stearate derivatives. However, for the ethoylated sorbitol esters the difference in static charge between the oleates and stearates is not clear. It should be noted that the amount of the finishes applied was two per cent, and it is very likely that a difference would be noted if smaller amounts of the finishes were used.

Table 5. A Comparison of Static Build-up and Decay of the Stearate and Oleate Finishes

Finish 2 Per Cent	40% Relative Humidity Build-up*	Decay*	65% Relative Humidity Build-up*	Decay*
Sorbitan Monooleate	4,300	0	1,500	0
Sorbitan Monostearate	7,200	0	1,300	0
Sorbitan Trioleate	26,700	600	24,600	800
Sorbitan Tristearate	60,700	11,700	42,700	6,700
Polyoxyethylene (5) Sorbitan Monooleate	750	25	450	50
Polyoxyethylene (4) Sorbitan Monostearate	1,400	25	400	0
Polyoxyethylene (20) Sorbitan Monooleate	1,150	50	200	0
Polyoxyethylene (20) Sorbitan Monostearate	1,100	50	300	0
Polyoxyethylene (20) Sorbitan Trioleate	1,700	25	1000	0
Polyoxyehtylene (20) Sorbitan Tristearate	1,700	0	200	0

* Each measurement was recorded in volts per meter after 15 minutes of build-up and after 15 minutes of decay.

Concentration of Finish

Four of the antistatic finishes, sorbitan trioleate, sorbitan monooleate, polyoxyethylene (5) sorbitan monooleate, and polyoxyethylene (20) sorbitan monooleate were applied to the carpet samples at concentrations of two per cent, and one half per cent based on the weight of fiber. The results are given in Table 6. As the concentration of finish is reduced, the static charge build-up is increased, and the static charge after 15 minutes of decay is also increased.

Apparently, at the higher finish concentration the moisture adsorption is increased and the surface of the carpet yarn is more completely coated with the finish. As the moisture adsorbed increases the electrical conductivity is increased resulting in a lower static charge build-up.

Table 6
The Effect of Finish Concentration on Static Build-Up and Decay at 65% Relative Humidity

Finish	2% Finish Build - up*	2% Finish Decay	0.5% Finish Build-up*	0.5% Finish Decay*
Sorbitan Trioleate	24,600	800	27,600	5,600
Sorbitan Monooleate	1,500	0	22,800	200
Polyoxyethylene (5) Sorbitan Monooleate	450	50	1,350	0
Polyoxyethylene (20) Sorbitan Monooleate	200	0	550	0

* Each measurement was recorded in volts per meter after 15 minutes of build-up and decay.

Effect of Relative Humidity

The effect of relative humidity on static charge build-up and decay is shown in Tables 7 and 8. It can be seen that in every case there is a decrease in the static build-up with an increase in relative humidity. After 15 minutes of decay the static charge remaining on the polypropylene is low and approximately the same except for the control sample and the sample with the sorbitan tristearate finish.

One explanation for the decrease in static build-up with an increase in relative humidity is that there is increased moisture adsorption on the surface of the polypropylene yarn. Since water increases the surface conductivity, there is a decrease in the static build-up as the relative humidity is increased.

Table 7
The Effect of Relative Humidity
on Static Build-Up*

Finish 2% O.W. F.	40% R.H.	65% R.H.
Sorbitan Monolaurate	600	50
Sorbitan Monopalmitate	2,100	400
Sorbitan Monooleate	4,300	1,500
Sorbitan Monostearate	7,200	1,300
Sorbitan Trioleate	26,700	24,600
Sorbitan Tristearate	60,700	42,700
Polyoxyethylene (4) Sorbitan Monolaurate	450	50
Polyoxyethylene (4) Sorbitan Monostearate	1,400	400
Polyoxyethylene (5) Sorbitan Monooleate	750	450
Polyoxyethylene (20) Sorbitan Monolaurate	2,100	400
Polyoxyethylene (20) Sorbitan Monopalmitate	1,800	400
Polyoxyethylene (20) Sorbitan Monooleate	1,100	200
Polyoxyethylene (20) Sorbitan Monostearate	1,150	300
Polyoxyethylene (20) Sorbitan Trioleate	1,700	1,000
Polyoxyethylene (20) Sorbitan Tristearate	1,600	200
Control	118,000	58,000

* Each measurement was recorded in volts per meter after 15 minutes of build-up

Table 8
Effect of Relative Humidity on Static Decay*

Finish 2% O.W.F.	40% R.H.	65% R.H.
Sorbitan Monolaurate	0	0
Sorbitan Monopalmitate	0	50
Sorbitan Monooleate	0	0
Sorbitan Monostearate	0	0
Sorbitan Trioleate	600	800
Sorbitan Tristearate	11,700	6,700
Polyoxyethylene (4) Sorbitan Monolaurate	0	0
Polyoxyethylene (4) Sorbitan Monostearate	25	0
Polyoxyethylene (5) Sorbitan Monooleate	25	50
Polyoxyethylene (20) Sorbitan Monolaurate	0	25
Polyoxyethylene (20) Sorbitan Monopalmitate	0	100
Polyoxyethylene (20) Sorbitan Monooleate	50	0
Polyoxyethylene (20) Sorbitan Monostearate	50	0
Polyoxyethylene (20) Sorbitan Trioleate	25	0
Polyoxyethylene (20) Sorbitan Tristearate	0	0
Control	77,000	35,000

* Each measurement was recorded in volts per meter after 15 minutes of decay.

Hydrophilic-lipophilic Balance

The non-ionic finishes used in this work represent materials which differ considerably in their hydrophilic-lipophilic character, that is, some are very hydrophilic and others are very lipophilic. Since these materials are used as emulsifiers, Atlas Chemical Industries, Inc. has developed a system for describing their hydrophilic-lipophilic nature.[23] This system called the HLB System is useful in choosing the particular product or mixture of products to use as emulsifiers.

The HLB number for a polyol fatty acid ester is calculated as follows:[24]

$$HLB = 20 \left(1 - S/A \right)$$

where

S = saponification number of the esters

A = acid number of the recovered fatty acid.

Low HLB values, therefore, correspond to very lipophilic substances and high values correspond to very hydrophilic substances.

A comparison of the HLB number and the static charge build-up and decay of the non-ionic finishes (2.0% concentration) used in this study is shown in Table 9. It can be seen that there is no clear direct relationship between the HLB number and the static charge build-up and decay. Apparently, with a two per cent concentration of finish the amount of ethylene oxide becomes the dominant factor in determining the antistatic effectiveness of the non-ionic finishes. Thus after four or five moles of ethylene oxide has been added to the finishes there is little difference in the static charge build-up or decay. However, at a 0.5 per cent concentration of finish, a clear relationship between the HLB number and the static charge build-up and decay is found. Table 10 shows that as the HLB number is increased, the static charge build-up is decreased and the static charge that remains after 15 minutes of decay is also decreased. This shows the importance of the hydrophilic-lipophilic balance in determining the antistatic properties of the non-ionic finishes at low concentrations.

Table 9
Comparison of HLB Number and Static Charge Build-up At 40% Relative Humidity

Finish 2 Per Cent O.W.F.	HLB	Build-Up*	Decay*
Sorbitan Trioleate	1.8	26,700	600
Sorbitan Tristearate	2.1	60,700	11,700
Sorbitan Monooleate	4.3	4,300	0
Sorbitan Monostearate	4.7	7,200	0
Sorbitan Monopalmitate	6.7	2,100	0
Sorbitan Monolaurate	8.6	600	0
Polyoxyethylene (4) Sorbitan Monostearate	9.6	1,400	25
Polyoxyethylene (5) Sorbitan Monooleate	10.0	750	25
Polyoxyethylene (20) Sorbitan Tristearate	10.5	1,700	0
Polyoxyethylene (20) Sorbitan Trioleate	11.0	1,700	25
Polyoxyethylene (4) Sorbitan Monolaurate	13.3	450	0
Polyoxyethylene (20) Sorbitan Monostearate	14.9	1,150	50
Polyoxyethylene (20) Sorbitan Monooleate	15.0	1,100	50
Polyoxyethylene (20) Sorbitan Monopalmitate	15.6	1,800	0
Polyoxyethylene (20) Sorbitan Monolaurate	16.7	2,100	0

* Each measurement was recorded in volts per meter after 15 minutes of of build-up and after 15 minutes of decay.

Table 10
Comparison of HLB Number and Static Charge Build-up and Decay at 65% Relative Humidity

Finish 0.5 Per Cent	HLB Number	Build-up*	Decay*
Sorbitan Trioleate	1.8	27,600	5,600
Sorbitan Monooleate	4.3	22,800	200
Polyoxyethylene (5) Sorbitan Monooleate	10.0	1,350	0
Polyoxyethylene (20) Sorbitan Monooleate	15.0	550	0
Polyethylene Glycol	$\approx$ 20	125	75

* Each measurement was recorded in volts per meter after 15 minutes of build-up and after 15 minutes of decay.

Durability of Non-Ionic Finishes

Tables 11 and 12 show the effect of a washing treatment on the durability of the non-ionic finishes. The data in Table 11 show that the washing treatment significantly increased the static build-up in all cases. Table 12 shows that the charge present after 15 minutes of decay was slightly increased in the majority of the finishes studied.

Apparently the washing treatment, which is actually a very accelerated test, removed some of the antistatic finish from the carpet samples. In other words, the non-ionic finishes are only semi-durable on polypropylene yarn.

Table 11
Durability of Non-Ionic Finishes at
65% Relative Humidity

Finish 2% O.W.F.	Build-Up* Unwashed	Washed
Sorbitan Monolaurate	50	14,300
Sorbitan Monopalmitate	400	5,100
Sorbitan Monooleate	1,500	17,100
Sorbitan Monostearate	1,300	18,600
Sorbitan Trioleate	24,600	54,600
Sorbitan Tristearate	42,700	42,700
Polyoxyethylene (4) Sorbitan Monolaurate	50	9,700
Polyoxyethylene (4) Sorbitan Monostearate	400	6,800
Polyoxyethylene (5) Sorbitan Monooleate	450	18,600
Polyoxyethylene (20) Sorbitan Monolaurate	400	10,500
Polyoxyethylene (20) Sorbitan Monopalmitate	400	13,100
Polyoxyethylene (20) Sorbitan Monooleate	200	11,600
Polyoxyethylene (20) Sorbitan Monostearate	300	6,600
Polyoxyethylene (20) Sorbitan Trioleate	1,000	17,100
Polyoxyethylene (20) Sorbitan Tristearate	200	9,400
Control	58,000	58,000

* Each measurement was recorded in volts per meter after 15 minutes of build-up.

Table 12
Durability of Non-Ionic Finishes at
65% Relative Humidity

Finish 2% O.W.F.	Decay* Unwashed	Washed
Sorbitan Monolaurate	0	150
Sorbitan Monopalmitate	50	0
Sorbitan Monooleate	0	50
Sorbitan Monostearate	0	25
Sorbitan Trioleate	800	8,600
Sorbitan Tristearate	6,700	9,200
Polyoxyethylene (4) Sorbitan Monolaurate	0	0
Polyoxyethylene (4) Sorbitan Monostearate	0	100
Polyoxyethylene (5) Sorbitan Monooleate	50	300
Polyoxyethylene (20) Sorbitan Monolaurate	25	750
Polyoxyethylene (20) Sorbitan Monopalmitate	100	300
Polyoxyethylene (20) Sorbitan Monooleate	0	600
Polyoxyethylene (20) Sorbitan Monostearate	0	50
Polyoxyethylene (20) Sorbitan Trioleate	0	200
Polyoxyethylene (20) Sorbitan Tristearate	0	100
Control	35,000	35,000

* Each measurement was recorded in volts per meter after 15 minutes of decay.

Comparison of Non-Ionic and Cationic Finishes

In order to determine the effectiveness of the non-ionic finishes as antistatic agents, they were compared with G-263 which is a widely used cationic antistatic finish. G-263 was applied to the carpet samples from a 0.25 per cent solution (35 per cent active ingredient). After 15 minutes of static build-up a charge of 350 volts per meter was recorded, and after 15 minutes of decay no static charge was detected. It can be seen in Tables 6 and 7 that it takes a much higher concentration of the non-ionic finishes to compare favorably with G-263.

A mixture of 0.25 per cent G-263 and 0.5 per cent sorbitan monooleate was applied to a polypropylene carpet sample. After 15 minutes of static build-up only 50 volts per meter was recorded, and after 15 minutes of static decay no charge was recorded. Thus G-263 while very effective at low concentrations, is also very effective when used in a mixture with the non-ionic sorbitan monooleate finish.

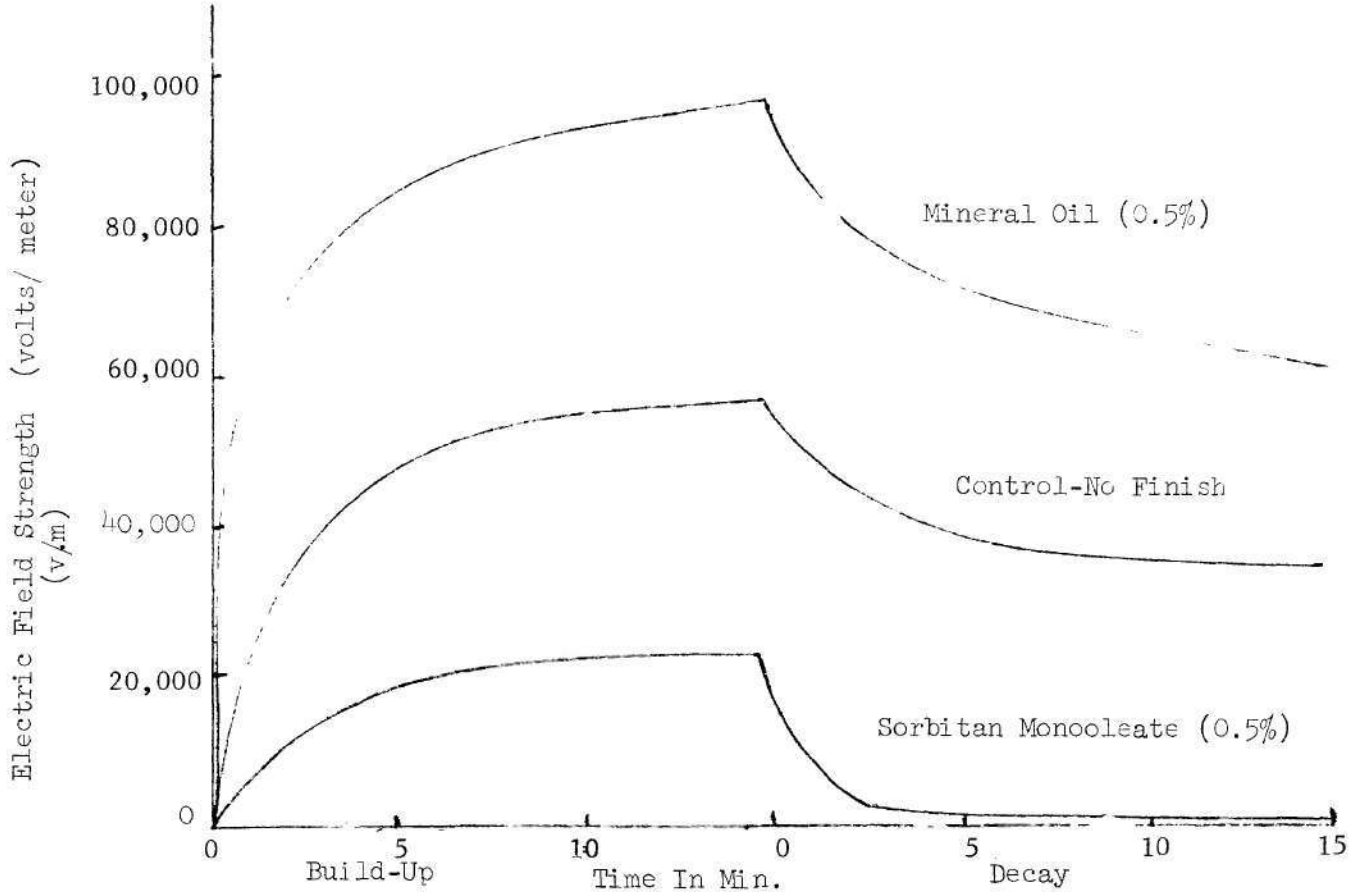

Figure 1. Electric Field Strength Build-Up and Decay Curves 65% Relative Humidity 80° Fahrenheit

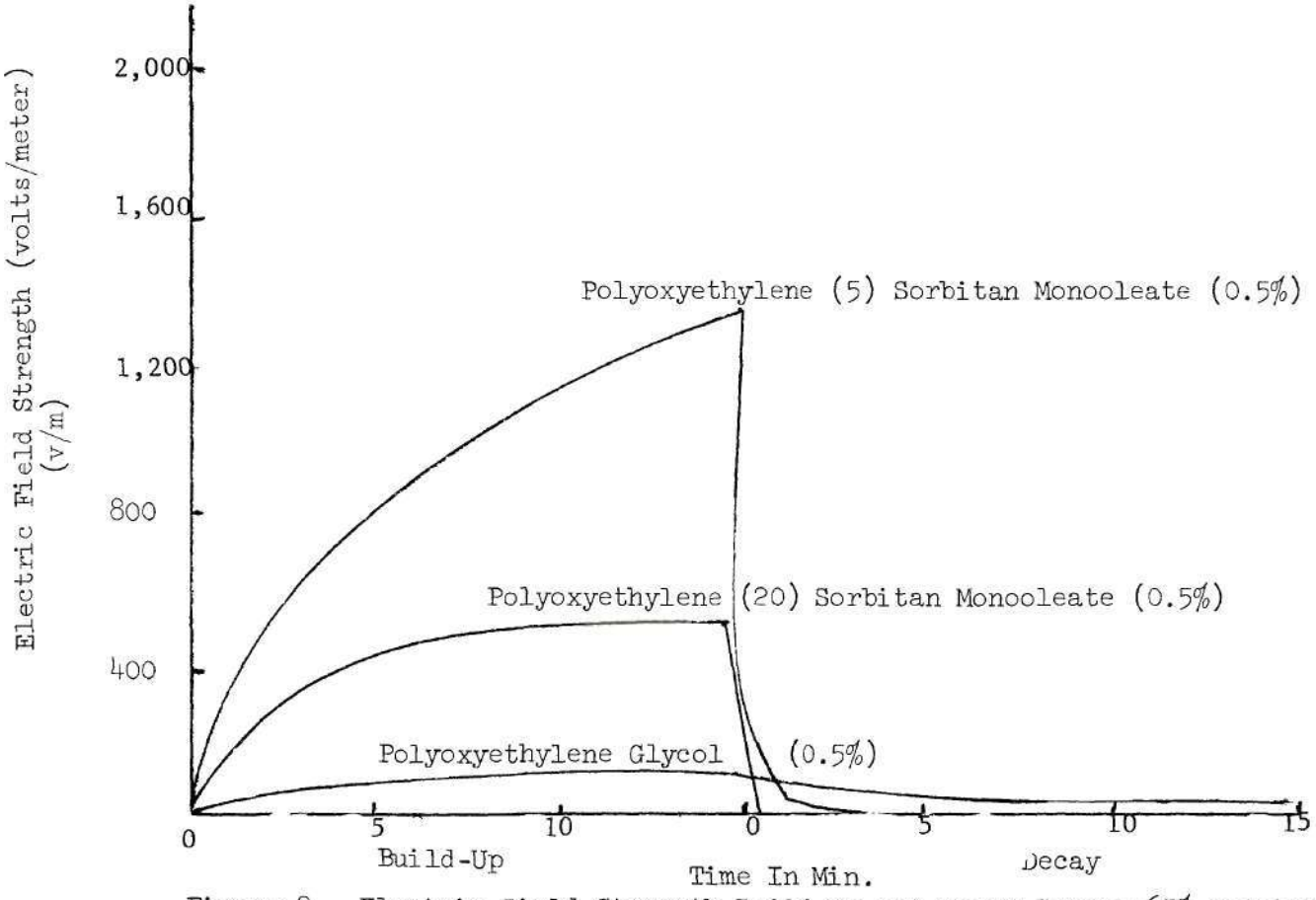

Figure 2. Electric Field Strength Build-Up and Decay Curves 65% Relative Humidity 80° Fahrenheit

CHAPTER V

CONCLUSIONS

The most important conclusions which can be drawn from this work are that the degree of static build-up in polypropylene carpets can be lowered by the application of non-ionic finishes, and the extent of lowering is a function of the hydrophilic-lipophilic nature of the finish, the amount of finish, and the conditions of relative humidity under which the measurements are made. With respect to chemical factors which differentiate these finishes the following specific conclusions can be drawn:

1. The degree of esterification plays an important role in the antistatic properties of the non-ionic finishes. The mono-esters perform much better than the tri-esters of sorbitol in every instance.

2. The degree of ethoxylation of the fatty acid esters of sorbitol is a very important factor in determining their antistatic properties. The general trend is that as the degree of ethoxylation is increased there is an increase in the antistatic properties of the finish.

3. The chain length of the organic acids that are reacted with sorbitol to form the ester derivatives has an influence on the static properties of the non-ionic finishes. The shorter chain laurates and palmitates reduce the static charge build-up more effectively than the stearate and oleate finishes.

4. The presence of unsaturation in the fatty acid chain results in better antistatic properties. When the non-ionic finishes are ethoxylated the effect of unsaturation in the fatty acid chain is minimized.

5. The concentration of finish is very important in determining the antistatic properties of the carpet samples. When the concentration of finish is reduced there is a substantial increase in the static charge build-up.

6. The atmospheric conditions under which the static measurements are made are very important when determining the effectiveness of non-ionic finishes. The static charge build-up decreases with increasing relative humidity.

7. The antistatic properties of the non-ionic finishes is determined by their hydrophilic-lipophilic balance (HLB number).

8. The non-ionic finishes studied were non-durable when applied to polypropylene carpeting. After the carpet samples were washed there were significant increases in the static charge build-up.

CHAPTER VI

RECOMMENDATIONS

All of the carpet samples used in this investigation were looped pile construction with face yarn of split film polypropylene. It would be of interest to determine the effect of using a polypropylene fiber with a round cross-section to determine the effect the shape of the fiber has on static generation and decay.

It would also be useful to study the durability of the antistatic finishes after they had been subjected to some type of wear test - either an accelerated wear test or an actual traffic test.

Another interesting study would be to determine the effects of heat ageing of the antistatic finish and its relationship to the static properties of the carpet.

Finally it is recommended that when carpet samples are studied, they should have secondary backings so that the pile yarn will not unravel from the primary backing when subjected to vigorous testing.

APPENDIX

Control Relative Humidity 40%

Time	Build-up	Decay
30 sec.	71,000	113,000
1 min.	78,000	108,000
2 min.	88,000	99,000
3 min.	97,000	94,000
4 min.	102,000	90,000
5 min.	110,000	88,000
6 min.	112,000	86,000
7 min.	113,000	85,000
8 min.	114,000	84,000
9 min.	114,000	83,000
10 min.	115,000	82,000
11 min.	116,000	81,000
12 min.	117,000	80,000
13 min.	118,000	79,000
14 min.	119,000	78,000
15 min.	119,000	77,000

Build-up and Decay Values are recorded in volts/meter.

Control Relative Humidity 65%

Time	Build-up	Decay
30 sec.	24,000	50,000
1 min.	29,000	48,000
2 min.	38,000	45,000
3 min.	43,000	43,000
4 min.	46,000	41,000
5 min.	48,000	40,000
6 min.	50,000	39,000
7 min.	51,000	38,000
8 min.	52,000	38,000
9 min.	53,000	37,000
10 min.	54,000	37,000
11 min.	54,000	36,000
12 min.	55,000	35,000
13 min.	56,000	35,000
14 min.	57,000	35,000
15 min.	58,000	35,000

Build-up and Decay values are recorded in volts/meter.

Control Relative Humidity 80%

Time	Build-up	Decay
30 sec.	18,000	38,000
1 min.	20,000	34,000
2 min.	23,000	31,000
3 min.	25,000	27,000
4 min.	27,000	25,000
5 min.	30,000	24,000
6 min.	33,000	23,000
7 min.	35,000	23,000
8 min.	37,000	22,000
9 min.	39,000	22,000
10 min.	40,000	22,000
11 min.	41,000	21,000
12 min.	42,000	21,000
13 min.	42,000	21,000
14 min.	42,000	21,000
15 min.	43,000	21,000

Build-up and Decay values are recorded in volts/meter.

Sorbitan Monopalmitate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	900	100	150	50	1,100	200
1	1000	50	150	50	2,100	100
2	1200	25	200	50	3,100	50
3	1300	25	200	50	3,600	0
4	1400	25	200	50	3,600	0
5	1500	0	250	50	3,600	0
6	1600	0	250	50	4,100	0
7	1700	0	300	50	4,100	0
8	1700	0	300	50	4,600	0
9	1800	0	300	50	4,600	0
10	1800	0	300	50	4,600	0
11	1900	0	350	50	4,600	0
12	1900	0	350	50	4,600	0
13	1900	0	350	50	5,100	0
14	2000	0	400	50	5,100	0
15	2100	0	400	50	5,100	0

Build-up and Decay values are recorded in volts/meter.

Sorbitan Monolaurate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	250	25	50	0	5,100	4,100
1	300	0	50	0	6,300	2,800
2	350	0	50	0	7,600	1,100
3	350	0	50	0	8,200	700
4	400	0	50	0	8,700	500
5	400	0	50	0	9,200	400
6	450	0	50	0	9,800	350
7	450	0	50	0	10,400	300
8	450	0	50	0	11,100	250
9	500	0	50	0	11,800	250
10	500	0	50	0	12,600	200
11	550	0	50	0	13,100	200
12	550	0	50	0	13,600	200
13	550	0	50	0	14,100	175
14	600	0	50	0	14,300	150
15	600	0	50	0	14,300	150

Build-up and Decay values are recorded in volts/meter.

Sorbitan Monostearate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	—	200	400	0	6,100	4,100
1	4600	100	550	0	9,100	2,300
2	5400	75	700	0	11,600	500
3	6300	50	800	0	13,100	300
4	6500	25	900	0	14,600	200
5	6700	0	1000	0	15,600	150
6	7000	0	1100	0	16,100	100
7	7000	0	1100	0	16,600	75
8	7000	0	1100	0	16,600	50
9	7000	0	1200	0	17,100	50
10	7000	0	1200	0	17,600	50
11	7000	0	1300	0	17,600	50
12	7200	0	1300	0	18,100	25
13	7200	0	1300	0	18,100	25
14	7200	0	1300	0	18,600	25
15	7200	0	1300	0	18,600	25

Build-up and Decay values are recorded in volts/meter.

Sorbitan Tristearate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	20,700	44,700	19,700	32,700	15,700	34,700
1	25,700	39,700	23,700	26,700	19,700	29,700
2	37,700	30,700	30,700	21,700	27,700	25,700
3	41,700	26,700	33,700	17,700	31,700	20,700
4	43,700	24,700	35,700	15,700	33,700	17,700
5	46,700	20,700	36,700	13,700	35,700	16,700
6	46,700	18,700	37,700	12,700	37,700	15,700
7	48,700	17,700	37,700	11,700	37,700	14,700
8	51,700	16,700	38,700	10,700	38,700	13,700
9	51,700	15,700	39,700	10,700	38,700	12,700
10	52,700	14,700	40,700	9,700	39,700	12,200
11	54,700	13,700	41,700	8,700	40,700	11,700
12	56,700	13,700	42,700	8,200	40,700	11,200
13	57,700	12,700	42,700	7,700	41,700	10,600
14	58,700	12,700	42,700	7,200	42,700	9,600
15	60,700	11,700	42,700	6,700	42,700	9,200

Build-up and Decay values are recorded in volts/meter.

Sorbitan Monooleate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	1900	100	600	25	8,100	8,600
1	2200	0	700	25	11,100	2,800
2	2300	0	800	0	12,600	500
3	2900	0	900	0	13,600	300
4	3600	0	900	0	14,600	200
5	3900	0	1000	0	15,100	150
6	4100	0	1100	0	15,600	125
7	4300	0	1200	0	16,100	100
8	4300	0	1300	0	16,100	100
9	4300	0	1300	0	16,100	75
10	4300	0	1300	0	16,600	50
11	4300	0	1400	0	16,600	50
12	4300	0	1400	0	16,600	50
13	4300	0	1400	0	17,100	50
14	4300	0	1400	0	17,100	50
15	4300	0	1500	0	17,100	50

Build-up and Decay values are recorded in volts/meter.

Sorbitan Trioleate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	18,000	14,000	15,000	15,000	25,600	37,600
1	23,000	10,000	17,000	11,000	34,600	31,600
2	23,000	6,500	20,000	7,000	39,600	26,600
3	23,000	4,500	22,000	5,500	40,600	22,600
4	23,000	3,500	23,000	4,500	41,600	17,600
5	23,000	2,700	24,000	5,800	44,600	15,600
6	23,000	2,400	24,000	3,200	46,600	14,600
7	23,000	1,900	24,600	2,400	48,600	13,600
8	23,000	1,400	24,600	2,000	20,600	12,600
9	24,000	1,200	24,600	1,800	50,600	11,600
10	26,000	1,000	24,600	1,400	50,600	10,600
11	26,000	900	24,600	1,100	51,600	10,600
12	26,700	900	24,600	1,000	52,600	9,600
13	26,700	800	24,600	900	52,600	9,600
14	26,700	700	24,600	900	53,600	9,100
15	26,700	600	24,600	800	54,600	8,600

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (20) Sorbitan Monolaurate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	1500	100	300	50	4,100	5,600
1	1700	75	300	50	5,100	4,700
2	1700	50	400	50	6,000	3,400
3	1700	50	400	50	6,600	2,500
4	1800	50	400	50	7,100	1,600
5	1800	50	400	50	7,500	1,400
6	1900	25	400	50	8,000	1,200
7	2000	25	400	50	8,300	1,100
8	2100	25	400	25	8,600	1,000
9	2100	25	400	25	8,900	900
10	2100	25	400	25	9,100	900
11	2100	25	400	25	9,400	900
12	2100	25	400	25	9,800	850
13	2100	0	400	25	10,100	800
14	2100	0	400	25	10,300	800
15	2100	0	400	25	10,500	750

Build-up and decay values are recorded in volts/meter.

Polyoxyethylene (4) Sorbitan Monolaurate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	250	0	50	0	3,400	800
1	250	0	50	0	4,600	300
2	300	0	50	0	5,800	100
3	300	0	50	0	6,300	50
4	300	0	50	0	6,700	25
5	300	0	50	0	7,000	0
6	350	0	50	0	7,300	0
7	350	0	50	0	7,600	0
8	350	0	50	0	7,800	0
9	400	0	50	0	8,000	0
10	400	0	50	0	8,200	0
11	450	0	50	0	8,400	0
12	450	0	50	0	8,700	0
13	450	0	50	0	9,000	0
14	450	0	50	0	9,300	0
15	450	0	50	0	9,700	0

Build-up and Decay values are reported in volts/meter.

Polyoxyethylene (20) Sorbitan Monopalmitate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	1800	25	300	125	4,600	5,200
1	1800	0	300	125	5,600	3,700
2	1800	0	350	125	6,800	2,300
3	1800	0	350	125	7,600	1,400
4	1800	0	350	125	8,200	1,100
5	1800	0	400	125	9,600	800
6	1800	0	400	125	10,100	700
7	1800	0	400	125	10,600	600
8	1800	0	400	100	11,100	500
9	1800	0	400	100	11,600	500
10	1800	0	400	100	11,600	450
11	1800	0	400	100	12,100	400
12	1800	0	400	100	12,600	350
13	1800	0	400	100	13,100	350
14	1800	0	400	100	13,100	300
15	1800	0	400	100	13,100	300

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (20) Sorbitan Monostearate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	650	100	100	0	1,400	1,600
1	750	100	150	0	1,900	700
2	850	75	200	0	3,300	400
3	950	75	250	0	4,200	200
4	950	75	250	0	4,800	200
5	950	50	300	0	5,100	150
6	1050	50	300	0	5,400	100
7	1050	50	300	0	5,700	100
8	1050	50	300	0	6,000	100
9	1050	50	300	0	6,100	75
10	1050	50	300	0	6,200	75
11	1150	50	300	0	6,300	75
12	1150	50	300	0	6,400	50
13	1150	50	300	0	6,500	50
14	1150	50	300	0	6,600	50
15	1150	50	300	0	6,600	50

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (4) Sorbitan Monostearate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	700	100	150	25	3,300	1,500
1	800	50	200	25	3,800	600
2	800	50	250	25	4,600	350
3	800	50	300	25	5,100	200
4	900	25	300	25	5,600	150
5	900	25	300	25	5,900	150
6	900	25	350	25	6,100	125
7	1000	25	400	0	6,200	100
8	1000	25	400	0	6,300	100
9	1100	25	400	0	6,400	100
10	1200	25	400	0	6,500	100
11	1300	25	400	0	6,600	100
12	1300	25	400	0	6,700	100
13	1300	25	400	0	6,800	100
14	1400	25	400	0	6,800	100
15	1400	25	400	0	6,800	100

Build-up and Decay values are recorded in volts/meter

Polyoxyethylene (20) Sorbitan Tristearate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	900	25	100	0	2,600	3,900
1	1000	0	100	0	3,800	3,600
2	1100	0	150	0	4,600	900
3	1200	0	150	0	5,300	600
4	1300	0	150	0	6,100	450
5	1300	0	150	0	6,600	350
6	1300	0	150	0	6,800	300
7	1400	0	150	0	7,100	250
8	1400	0	150	0	7,400	200
9	1500	0	150	0	7,800	150
10	1500	0	200	0	8,100	150
11	1600	0	200	0	8,300	100
12	1600	0	200	0	8,600	100
13	1600	0	200	0	8,900	100
14	1600	0	200	0	9,100	100
15	1600	0	200	0	9,400	100

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (20) Sorbitan Monooleate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	900	150	100	0	4,400	5,700
1	900	100	100	0	5,600	4,700
2	900	75	150	0	6,600	3,200
3	900	75	150	0	7,800	2,500
4	900	50	150	0	8,600	1,700
5	1000	50	200	0	9,600	1,500
6	1000	50	200	0	10,100	1,300
7	1000	50	200	0	10,600	1,100
8	1000	50	200	0	11,100	1,000
9	1000	50	200	0	11,600	900
10	1100	50	200	0	11,600	800
11	1100	50	200	0	11,600	800
12	1100	50	200	0	11,600	700
13	1100	50	200	0	11,600	700
14	1100	50	200	0	11,600	700
15	1100	50	200	0	11,600	600

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (5) Sorbitan Monooleate 2%

Time in Min.	40% Relative Humidity Not washed Build-up	Decay	65% Relative Humidity Not Washed Build-up	Decay	Washed Build-up	Decay
0.5	300	75	200	50	9,600	9,600
1	400	50	250	50	11,600	5,600
2	450	50	300	50	13,600	3,100
3	500	50	300	50	14,600	1,600
4	550	50	350	50	15,600	1,100
5	550	25	400	50	16,600	900
6	600	25	450	50	16,600	800
7	650	25	450	50	17,600	700
8	650	25	450	50	17,600	600
9	650	25	450	50	17,600	500
10	650	25	450	50	18,100	450
11	650	25	450	50	18,100	400
12	700	25	450	50	18,600	400
13	700	25	450	50	18,600	350
14	700	25	450	50	18,600	300
15	750	25	450	50	18,600	300

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (20) Sorbitan Trioleate 2%

Time in Min.	40% Relative Humidity Not Washed		65% Relative Humidity Not Washed		Washed	
	Build-up	Decay	Build-up	Decay	Build-up	Decay
0.5	800	100	500	25	6,000	6,200
1	1000	50	600	25	7,800	4,200
2	1200	50	700	25	10,000	2,500
3	1300	50	700	25	12,000	1,300
4	1400	50	800	0	13,000	1,000
5	1500	50	850	0	13,500	800
6	1600	25	850	0	14,000	600
7	1600	25	900	0	14,500	500
8	1600	25	900	0	15,000	400
9	1700	25	1000	0	15,000	400
10	1700	25	1000	0	16,000	300
11	1700	25	1000	0	16,000	250
12	1700	25	1000	0	16,000	250
13	1700	25	1000	0	16,500	200
14	1700	25	1000	0	16,500	200
15	1700	25	1000	0	17,100	200

Build-up and Decay values are recorded in volts/meter.

G-263 .25%
At 65% Relative Humidity

Time	Washed Sample		Unwashed Sample	
	Build-up	Decay	Build-up	Decay
30 sec.	10,000	29,000	0	25
1 min.	14,000	26,000	0	0
2 min.	18,000	22,000	0	0
3 min.	21,000	18,000	50	0
4 min.	23,000	16,000	50	0
5 min.	25,000	15,000	75	0
6 min.	27,000	14,000	100	0
7 min.	29,000	13,500	150	0
8 min.	31,000	13,000	175	0
9 min.	32,000	12,500	200	0
10 min.	33,000	12,000	225	0
11 min.	34,000	11,500	250	0
12 min.	35,000	11,500	275	0
13 min.	36,000	11,000	300	0
14 min.	37,000	11,000	325	0
15 min.	37,000	11,000	350	0

Build-up and Decay values are recorded in volts/meter.

Sorbitan Trioleate 0.5%
65% Relative Humidity

Time	Build-up	Decay
30 sec.	8,100	18,600
1 min.	11,100	16,600
2 min.	14,100	14,600
3 min.	16,600	13,600
4 min.	18,100	12,100
5 min.	19,100	11,100
6 min.	20,100	10,600
7 min.	20,600	9,100
8 min.	21,600	8,100
9 min.	22,600	7,100
10 min.	23,600	6,600
11 min.	24,600	6,300
12 min.	25,600	6,100
13 min.	26,600	5,900
14 min.	27,100	5,700
15 min.	27,600	5,600

Build-up and Decay values are recorded in volts/meter

Sorbitan Monooleate 0.5%
G-263 65% Relative Humidity

Time	Build-up	Decay
30 sec.	50	0
1 min.	50	0
2 min.	50	0
3 min.	50	0
4 min.	50	0
5 min.	50	0
6 min.	50	0
7 min.	50	0
8 min.	50	0
9 min.	50	0
10 min.	50	0
11 min.	50	0
12 min.	50	0
13 min.	50	0
14 min.	50	0
15 min.	50	0

Build-up and Decay values are recorded in volts/meter.

Sorbitan Monooleate 2%
Relative Humidity 80%

Time	Build-up	Decay
30 sec.	50	0
1 min.	50	0
2 min.	50	0
3 min.	50	0
4 min.	50	0
5 min.	50	0
6 min.	50	0
7 min.	50	0
8 min.	50	0
9 min.	50	0
10 min.	50	0
11 min.	50	0
12 min.	50	0
13 min.	50	0
14 min.	50	0
15 min.	50	0

Build-up and Decay values are recorded in volts/meter.

Sorbitan Monstearate 2%
Relative Humidity 80%

Time	Build-up	Decay
30 sec.	0	0
1 min.	0	0
2 min.	25	0
3 min.	50	0
4 min.	50	0
5 min.	50	0
6 min.	100	0
7 min.	100	0
8 min.	100	0
9 min.	100	0
10 min.	100	0
11 min.	100	0
12 min.	100	0
13 min.	100	0
14 min.	100	0
15 min.	100	0

Build-up and Decay values are recorded in volts/meter.

Sorbitan Tristearate 2%
Relative Humidity 80%

Time	Build-up	Decay
30 sec.	6,600	13,600
1 min.	8,100	9,600
2 min.	10,600	7,100
3 min.	12,100	5,400
4 min.	13,100	4,600
5 min.	14,100	4,200
6 min.	14,600	3,900
7 min.	15,600	3,400
8 min.	16,600	3,100
9 min.	17,100	2,900
10 min.	17,600	2,600
11 min.	17,600	2,400
12 min.	18,100	2,300
13 min.	18,600	2,200
14 min.	19,100	2,100
15 min.	19,600	2,000

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (20) Sorbitan Trioleate 2%
Relative Humidity 80%

Time	Build-up	Decay
30 sec.	0	0
1 min.	0	0
2 min.	50	0
3 min.	50	0
4 min.	50	0
5 min.	50	0
6 min.	100	0
7 min.	100	0
8 min.	100	0
9 min.	100	0
10 min.	100	0
11 min.	100	0
12 min.	100	0
13 min.	100	0
14 min.	100	0
15 min.	100	0

Build-up and Decay values are recorded in volts/meter.

Sorbitan Trioleate 2%
Relative Humidity 80%

Time	Build-up	Decay
30 sec.	6,600	8,600
1 min.	8,600	6,100
2 min.	11,600	4,100
3 min.	12,600	3,200
4 min.	13,600	2,700
5 min.	13,600	2,000
6 min.	14,600	1,600
7 min.	14,600	1,300
8 min.	14,600	1,100
9 min.	15,600	1,000
10 min.	16,100	900
11 min.	16,600	700
12 min.	16,600	600
13 min.	16,600	500
14 min.	16,600	450
15 min.	16,600	400

Build-up and Decay values are recorded in volts/ meter.

Sorbitan Monooleate 0.5%
65% Relative Humidity

Time	Build-up	Decay
30 sec.	6,800	10,600
1 min.	10,000	6,600
2 min.	13,600	3,900
3 min.	15,600	1,800
4 min.	17,600	1,300
5 min.	18,100	1,000
6 min.	18,600	800
7 min.	19,100	600
8 min.	19,600	500
9 min.	20,100	400
10 min.	20,900	350
11 min.	21,600	300
12 min.	22,100	275
13 min.	22,600	250
14 min.	22,600	225
15 min.	22,800	200

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (5) Sorbitan Monooleate 0.5%
65% Relative Humidity

Time	Build-up	Decay
30 sec.	300	100
1 min.	400	50
2 min.	500	25
3 min.	600	25
4 min.	700	0
5 min.	800	0
6 min.	900	0
7 min.	1000	0
8 min.	1050	0
9 min.	1150	0
10 min.	1200	0
11 min.	1250	0
12 min.	1250	0
13 min.	1300	0
14 min.	1350	0
15 min.	1350	0

Build-up and Decay values are recorded in volts/meter.

Polyoxyethylene (20) Sorbitan Monooleate 0.5%
65% Relative Humidity

Time	Build-up	Decay
30 sec.	200	0
1 min.	250	0
2 min.	300	0
3 min.	350	0
4 min.	400	0
5 min.	450	0
6 min.	500	0
7 min.	550	0
8 min.	550	0
9 min.	550	0
10 min.	550	0
11 min.	550	0
12 min.	550	0
13 min.	550	0
14 min.	550	0
15 min.	550	0

Build-up and Decay values are recorded in volts/meter.

Mineral Oil .5%
At 65% Relative Humidity

Time	Build-up	Decay
30 sec.	50,000	87,000
1 min.	65,000	82,000
2 min.	74,000	78,000
3 min.	80,000	75,000
4 min.	84,000	72,000
5 min.	86,000	71,000
6 min.	87,000	70,000
7 min.	88,000	69,000
8 min.	89,000	68,000
9 min.	90,000	67,000
10 min.	91,000	66,000
11 min.	92,000	65,000
12 min.	93,000	64,000
13 min.	94,000	63,000
14 min.	95,000	62,000
15 min.	96,000	61,000

Build-up and Decay values are recorded in volts/meter.

Polyethylene Glycol 0.5%
65% Relative Humidity

Time	Build-up	Decay
30 sec.	50	100
1 min.	75	100
2 min.	75	100
3 min.	75	100
4 min.	100	75
5 min.	100	75
6 min.	100	75
7 min.	100	75
8 min.	100	75
9 min.	100	75
10 min.	100	75
11 min.	100	75
12 min.	100	75
13 min.	125	75
14 min.	125	75
15 min.	125	75

Build-up and Decay values are recorded in volts/meter.

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